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The focus of the project was to develop advanced Automatic Target Recognition (ATR) algorithms to interface with the existing ATR technology at NGC. As outlined in the project proposal, the specific goals of this project were the following:
(1) Development of wavelet-based denoising and compression algorithms by Rice CML for SAR and SONAR images. (2) Development of wavelet-based algorithms for ATR in SAR and SONAR data by Rice CML. (3) Transfer of Rice denoising/compression/detection software to NGC for testing on SAR and SONAR data. (4) Application of Rice software in a real-time demo. (5) Establishment of a password protected Rice CML ATR website to facilitate information sharing between all parties and technology transfer from Rice to NGC.

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Rice-Northrop Grumman Joint
Real Time Wavelet-Based ATR Project
Final Progress Report to DARPA

Raymond O. Wells, Jr. (Rice), Richard G. Baraniuk (Rice),
and Paul H. Haley (NGC)

October 2000

This is the final report for the DARPA-AFOSR grant F49620-97-0513. It summarizes our
research effort over the past three years in Real Time Wavelet-Based ATR. This project
was a joint effort between Rice Computational Mathematics Laboratory (CML) and
Northrop Grumman Corporation (NGC). The personnel directly involved in this project
were (from Rice) Raymond Wells (PI), Richard Baraniuk (co-PI), Jun Tian (research sci-
entist), Vidya Venkatachalam (NGC-supported postdoc), Felix Fernandes (graduate stu-
dent), and Justin Romberg (graduate student), and (from NGC) Phil Schweizer, Robert
Mitchell, Paul Haley (PI), Andrew Miklich, and Mike Hoffelder. Sidney Burrus (co-PI)
was actively involved in the project until he became Dean of Engineering at Rice in
Summer 1998.

1 Project Goals

The focus of the project was to develop advanced Automatic Target Recognition (ATR)
algorithms to interface with the existing ATR technology at NGC. As outlined in the
project proposal, the specific goals of this project were the following:

1. Development of wavelet-based denoising and compression algorithms by Rice CML
   for SAR and SONAR images.

2. Development of wavelet-based algorithms for ATR in SAR and SONAR data by
   Rice CML.

3. Transfer of Rice denoising/compression/detection software to NGC for testing on
   SAR and SONAR data.

4. Application of Rice software in a real-time demo.

5. Establishment of a password protected Rice CML ATR website to facilitate informa-
   tion sharing between all parties and technology transfer from Rice to NGC.
2 Research Accomplishments

All goals put forth in the project proposal have been achieved during the course of the last three years. The research has been presented at major conferences (ICASSP, SPIE, ICIP, etc.), and it also appears in several leading journal publications. A listing of recent publications by Rice personnel supported by the DARPA grant is provided at the end of the report. This provides a flavor of the current research effort at Rice.

1. Rice has developed algorithms to perform wavelet-based image compression and denoising. These algorithms were then incorporated in the preprocessing stage in ATR schemes. The algorithms tested successfully for detection performance using CFAR on SAR and SONAR data provided by NGC. An example of detection performance using the Rice wavelet-based denoising algorithm on SONAR data with ground truths provided by NGC is shown in Figure 1. Figure 2 shows an example of detection performance on the same SONAR data, compressed to a ratio of 40:1.

Rice has transferred the developed software to NGC for testing on classified and unclassified data. The transfer process has been smooth, with NGC reporting no problems in applying the codes. The routines have tested successfully on actual field data. A rigorous testing and documentation of the results of applying the Rice CFAR denoising/detection algorithm on actual SONAR and SAR data was performed by NGC, as proposed in the last annual project report. A part of this work was presented by Mike Hoffelder at the 14th SPIE Aerosense Conference in Orlando in April 2000 [11].

2. Rice has also developed algorithms for wavelet-based ATR as proposed in the proposal. The main objective here was the classification of clutter in SAR images, for the purpose of prescreening in an ATR scheme. As proposed in the last annual report, Rice has successfully developed a new approach to ATR based on wavelet-domain hidden Markov trees (HMTs). This has been applied to SAR data with very good results. Details of this work can be obtained from [12]. In addition, Rice has also developed an algorithm to perform unsupervised SAR image segmentation based on Poisson approximations, which was also presented at the 14th annual SPIE Aerosense conference [13]. Both these approaches have been found by NGC to be very useful for prescreening applications in their ATR schemes. Figure 3 shows an example of the segmentation of a SAR image from the MSTAR data set using both these schemes.
3. Significant progress has been made on research on wavelet-based pseudo power signatures (PPSs) for ATR [15],[16]. PPSs offer invariance to the size, location, and magnitude of targets for potentially more robust detection and classification.

4. Work on optimally shift-invariant, directionally selective complex wavelet bases is progressing satisfactorily with some exciting new results reported [17], [18]. These new wavelet bases are compatible with the CFAR, HMT, and PPS techniques and will endow them with shift-invariance and directional selectivity, thereby improving overall performance.

5. One of the principal goals of this research effort was the deployment of Rice software in real-time ATR applications by NGC. On that front, we note that ICompress, a copyrighted wavelet image compression algorithm developed by Rice CML, has been deployed in a US Navy minehunting system. Northrop Grumman Oceanic Systems in Annapolis, Maryland is incorporating ICompress into the US Navy's AN/AQS-14A Search Sonar System operated from the MH-53E helicopter. The algorithm is being used for compressing side look sonar data for real time transmission from the helicopter to a shore or shipboard station over an HF radio link in minehunting operations. The use of wavelet compression is reducing the transmission time for the sonar snippets from three and a half minutes to under fourteen seconds (successfully using 16 to 1 compression). This upgrade was installed into all US Navy systems in the March-April timeframe.

6. Finally, Rice CML has established a password-protected ATR website with URL www.cml.rice.edu/atrr to interactively demonstrate new algorithms, educate NGC personnel on new developments, and transfer technology in a smooth and timely fashion.

3 Project milestones

A significant component of the project has been the active interaction between the Rice, NGC, and DARPA personnel by means of a series of meetings, and telephone and email communications. This has resulted in Rice developing algorithms specifically targeted to meeting the needs expressed by the NGC personnel. The joint effort produced three papers [11],[12],[13] presented at the 14th SPIE Aerosense Conference in Orlando, FL, in April 2000. A timeline of the interaction is summarized in Table 1.

During the course of the project, several students were awarded M.S. and Ph.D. degrees. Students who received degrees and were either fully or partially supported
Table 1: ATR project meetings

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
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<tbody>
<tr>
<td>Paul Haley visit to Rice</td>
<td>November 1996</td>
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<tr>
<td>ATR project kick-off meeting in Washington DC</td>
<td>April 1998</td>
</tr>
<tr>
<td>Richard Baraniuk visit to DARPA</td>
<td>June 1998</td>
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<tr>
<td>Jun Tian and Vidya Venkatachalam visit to NGC</td>
<td>October 1998</td>
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<tr>
<td>Paul Haley visit to Rice</td>
<td>January 1999</td>
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<tr>
<td>Raymond Wells visit to DARPA</td>
<td>February 1999</td>
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<tr>
<td>Rice-NGC meeting with DARPA</td>
<td>April 1999</td>
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<tr>
<td>NGC visit to Rice</td>
<td>June 1999</td>
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<tr>
<td>DARPA, AFOSR and NGC visit to Rice</td>
<td>February 2000</td>
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</tbody>
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by this grant, or worked in areas complementary to the grant research areas are:

- Matthew Crouse - Ph.D. (May 1999)
- Roger Claypoole - Ph.D. (May 2000)
- Justin Romberg - M.S. (May 1999)
- Ramesh Neelamani - M.S. (May 1999)


Figure 1: (a) Original SONAR image, (b) With ground truth, (c) Denoised SONAR image, (d) CFAR Detection performance using denoised image
Figure 2: (a) Original SONAR image, (b) With ground truth, (c) 40:1 Compressed SONAR image, (c) CFAR Detection performance using compressed image
Figure 3: (a) Original SAR MSTAR data HB06170 containing forest and field imagery, (b) Segmented data using HMT, (c) Segmented data using Poisson approximations